State, challenges and options of pedogenetic modelling

at pedon and landscape scales

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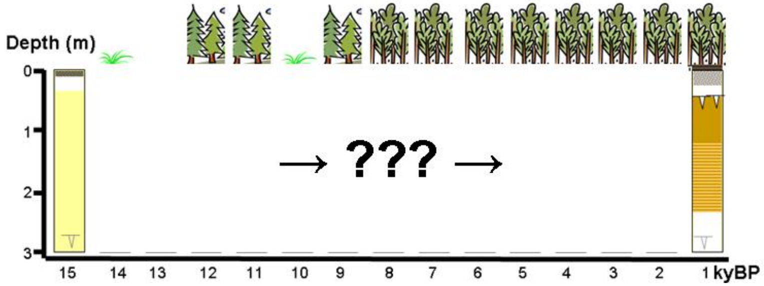
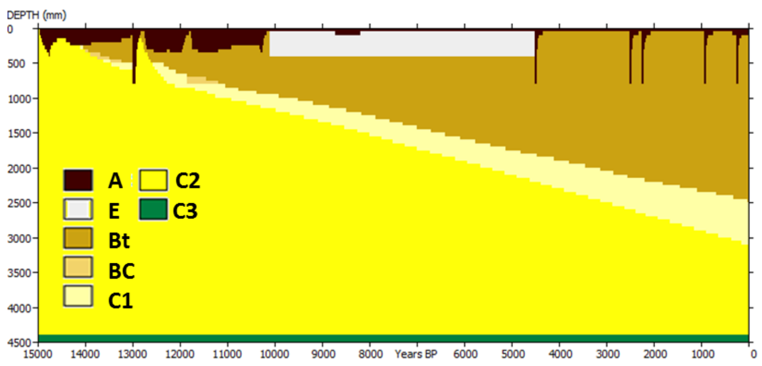
1. What is pedogenetic modelling
2. Schools of soil-landscape PM
   - 2 examples
3. State of progress
   - literature scan
4. Challenges
   - Per school of PM
   - Caused by temporal extent of PM





Pedogenetic modelling

- Correlated co-evolution of multiple soil properties over decade .. millennium time extents *(traditional purpose to understand horizonation & for classification)*
- Until recently: mostly single issue models
  - acidification, C, nutrient leaching, biocide leaching, agronomic, … models
  - Integrated assessment of soil development under Global Change was multi-model study, possibly lacking feedbacks
- Is a complete pedogenetic model GC-ready?

Pedogenetic modelling

Pedogenetic models respond to soil forming factors (CLORPT) acting as BC

Factor	Boundary condition	Process	Soil regime
Climate	Temperature	Heat flow	Temperature regime
	Atmospheric deposition	Solute flow	Solution composition
	Precipitation, Evaporation	Water flow	Moisture regime
Organisms	(Man regulated) Plant cover	Water flow	
	(Man regulated) Plant production	C-cycling	C-status
		Nutrient cycling	Solution/adsorption/precipitate status
	Man: Fertilization	Solute flow	
	Treefall, Faunal activity	Bioturbation	Solid matter distribution
	Man: Tillage	Turbation	
Relief	Truncation	Erosion	
	Burial	Deposition	
	Exposition (radiation, precipitation)	Water flow	Moisture regime
Parent material	Initial Mineralogy	Chem. weathering	Mineralogical composition
	Initial Texture	Phys. Weathering	Texture profile
		Clay migration	
	Initial Chemistry	Chemical equilibriums	Solution/adsorption/precipitate status
Time	Changes in boundary conditions	Process dynamics	Regime dynamics

Horizonation, Classification

Global change modelling of soils

Global change = change in climate + human modification of other aspects of the global environment (compartment: Soil)

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GC-affected | Indirectly GC-affected

Management, ES services

→ "GC-ready" soil models should respond to same BC's and comprise the same processes as complete pedogenetic models

Schools of soil-landscape P.M.

1. (Spatially distributed) 1D+t pedogenetic models
   - Often developed from leaching models → include hydrology
   - Most cases: Mechanistic process descriptions
     No spatial interaction
   - Examples: Kirkby, *Orthod*, *Witch*, Runge, *HP1*, *SoilGen*

2. (Spatially explicit) 2D+t and 3D+t pedogenetic models
   - Developed from mass wasting/soil production models
   - Most cases: No hydrology
     Spatial interaction at upper boundary
     Empirical process descriptions
   - Examples: Salvador, Sommer, *mARM3D*, *MILESD*

1-D example: *SoilGen*

CLORPT-proof?

Factor	Boundary condition	Process	Mech	Emp
Climate	Temperature	Heat flow		
	Atmospheric deposition	Solute flow		
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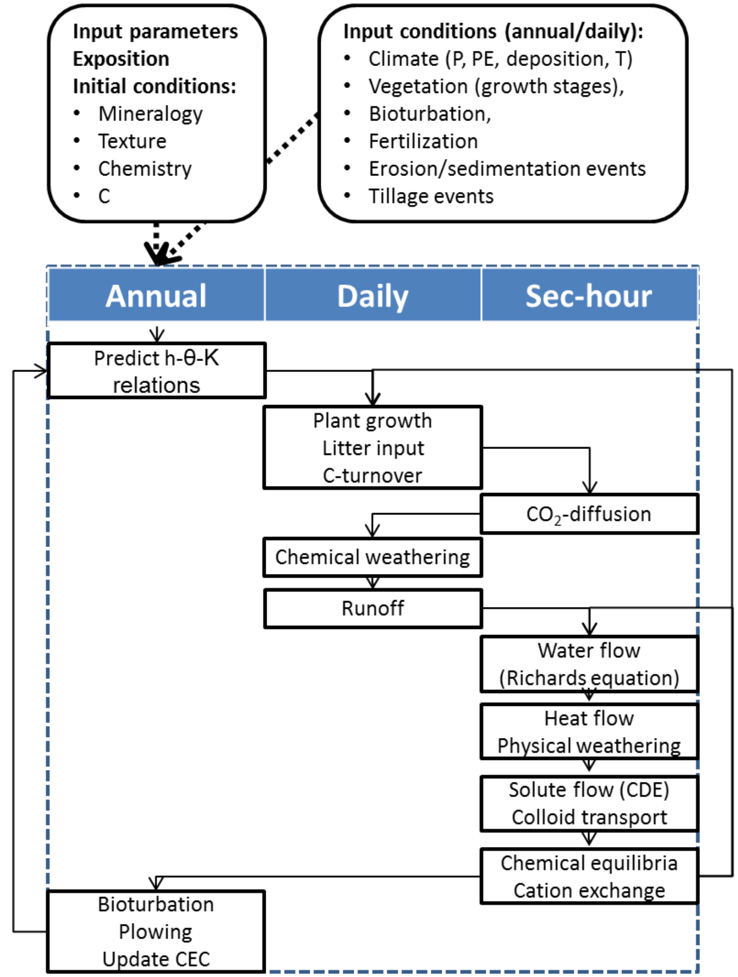
	Initial Chemistry	Chemical equilibr.		
Time	Changes in boundary conditions			

Model structure



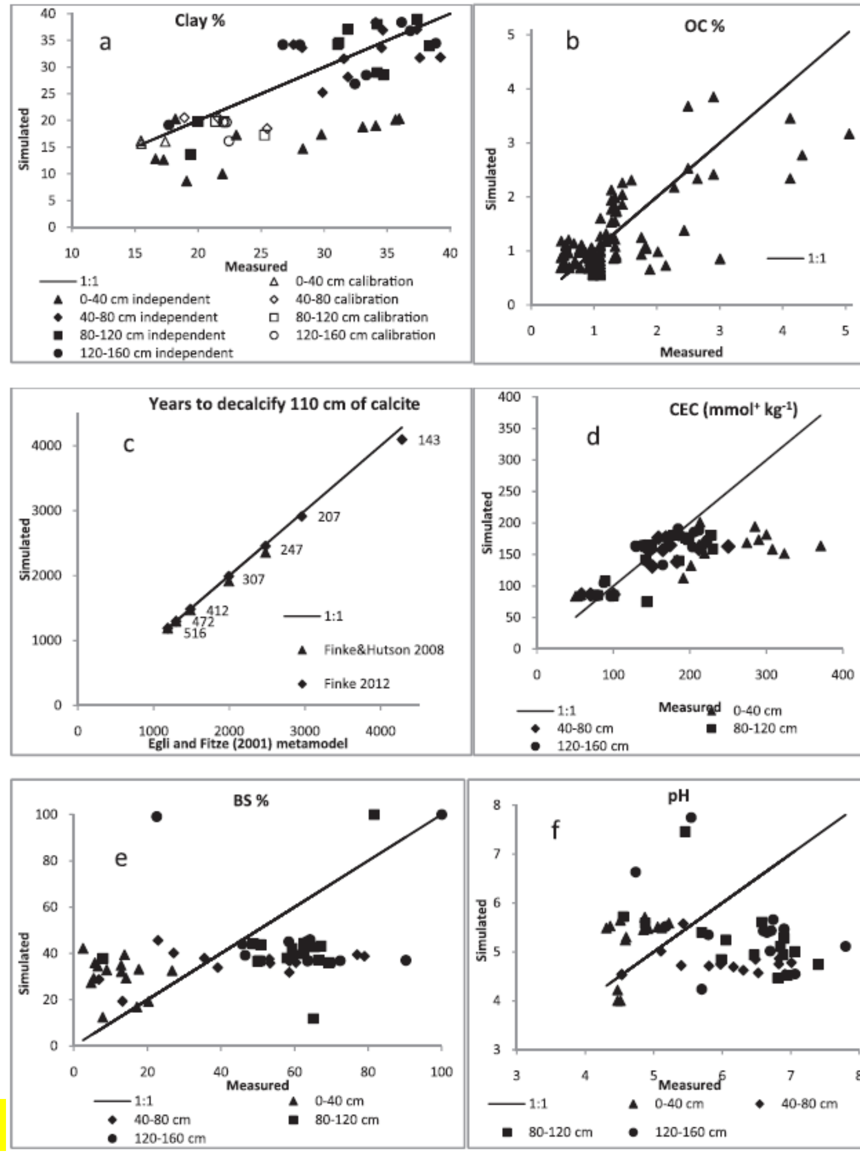
Finke&Hutson, 2008; Finke, 2012

1-D example: *SoilGen*

Verification status

Parameter	Calibration	Quantitative field data verification
SOC	Yu et al. 2013	Finke&Hutson 2008; Yu et al. 2013; Zwertvaegher et al. 2013; Opolot et al. 2014
Calcite	Finke&Hutson 2008; Finke 2012; Zwertvaegher et al. 2013	Zwertvaegher et al. 2013; Opolot et al. 2014
Clay	Finke, 2012; Finke et al., in press	Finke, 2012; Sauer et al. 2012; Zwertvaegher et al. 2013; Opolot et al. 2014; Finke et al., in press
CEC, BS, pH	-	Sauer et al. 2012; Zwertvaegher et al. 2013; Opolot et al. 2014

Good: Texture, OC, calcite
Fair: CEC
Poor: BS, pH
Emphasis: improved weathering + chemistry

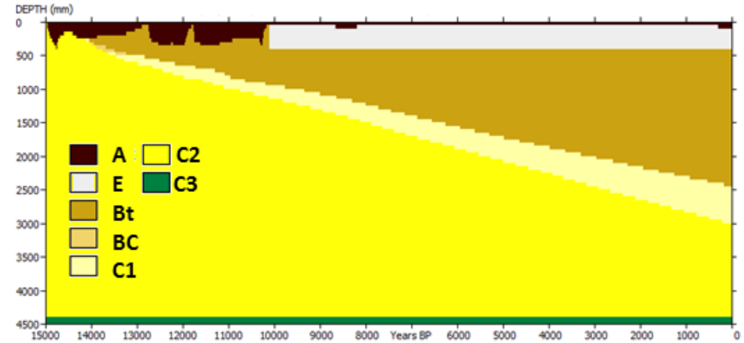


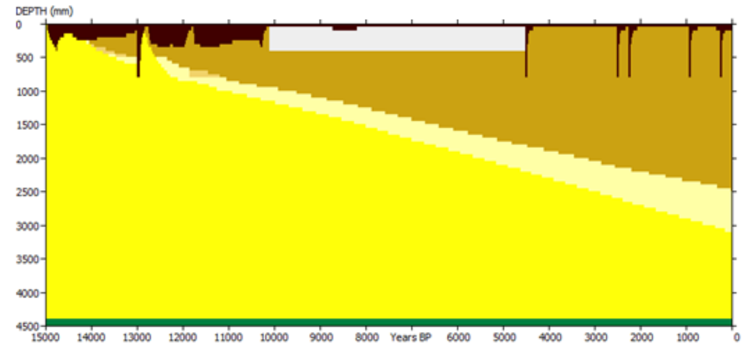
Opolot et al., 2014

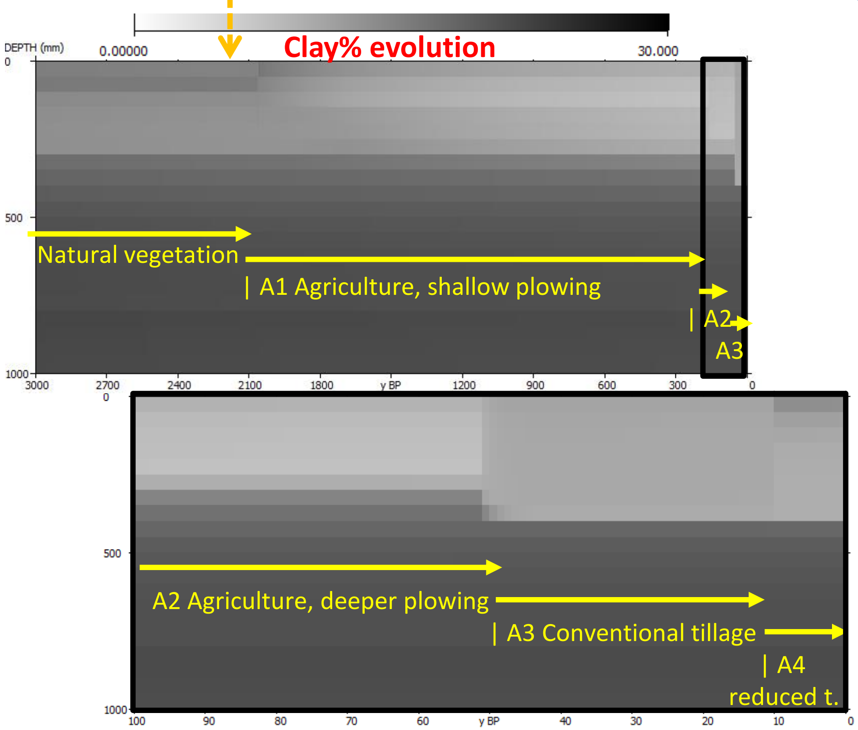
1-D example: *SoilGen*

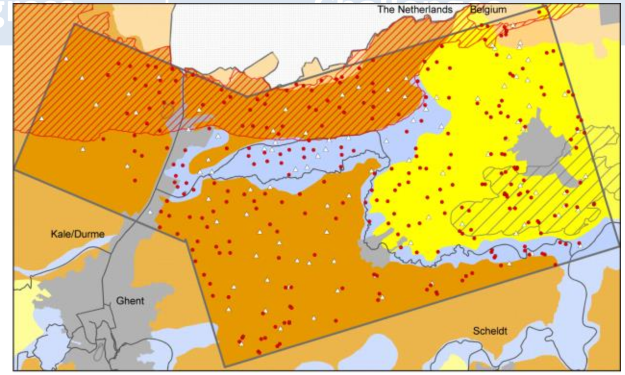
Cases

Case	Reference
Climosequence	Finke&Hutson, 2008
Toposequence	Finke, 2012
Chronosequences	Sauer et al., 2012
Soilscape reconstruction	Zwertvaegher et al., 2013
Horizon development	Finke et al., 2013
Agriculture and lessivage	Finke et al., in press Cornu et al. in prep.







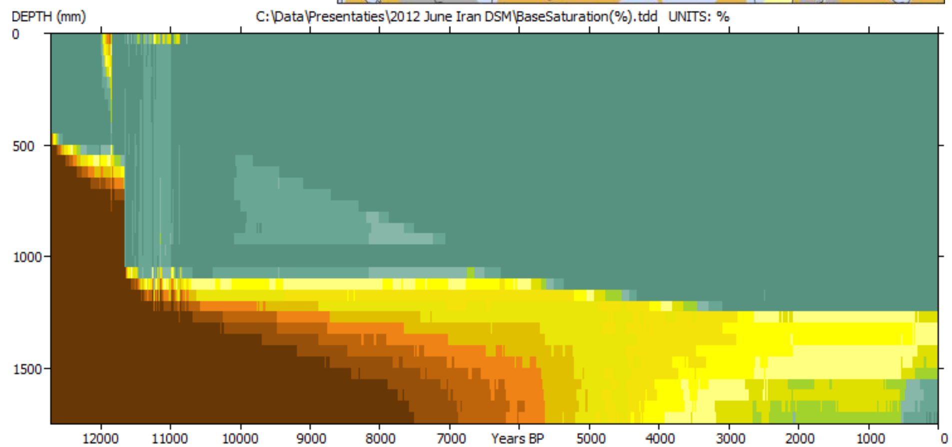


Distributed 1-D

SoilGen for Soilscape genesis

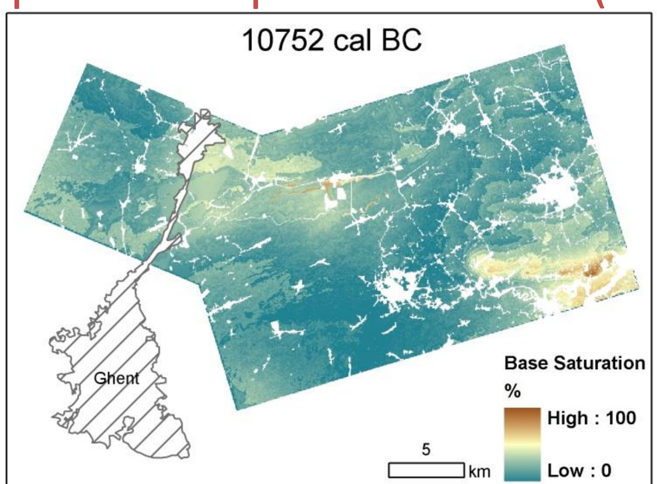
After reconstruction of hydrology (Modflow):

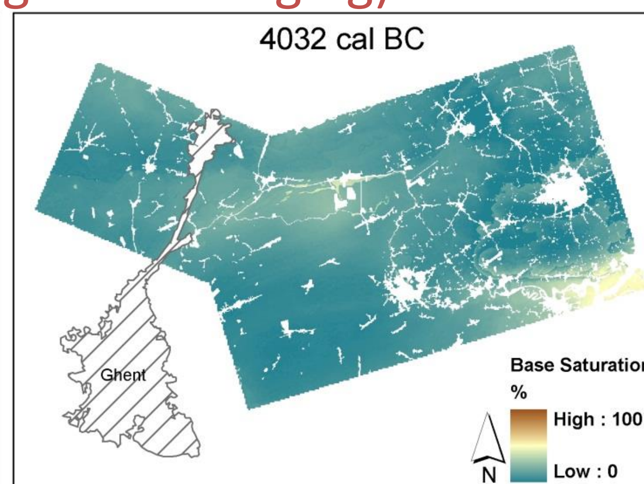
a. Simulation soil development at 100 locations (SoilGen)
- Rapid decalcification
- Decreasing Base Saturation →



b. Mapping soil properties at points in time (regression kriging)

BS% in topsoil of lateglacial coversand





Zwertvaegher et al., 2013

3-D example: *MILESD*

CLORPT-proof?

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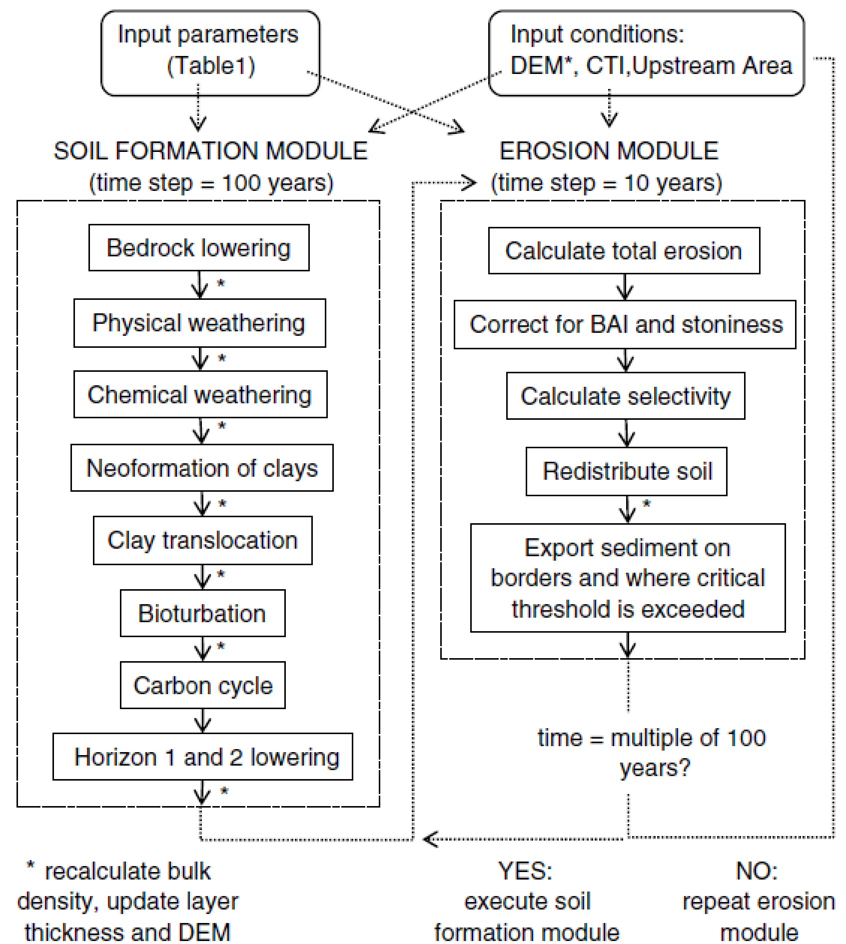
Model structure



Vanwalleghem et al., 2013

3-D example: *MILESD*

Verification status

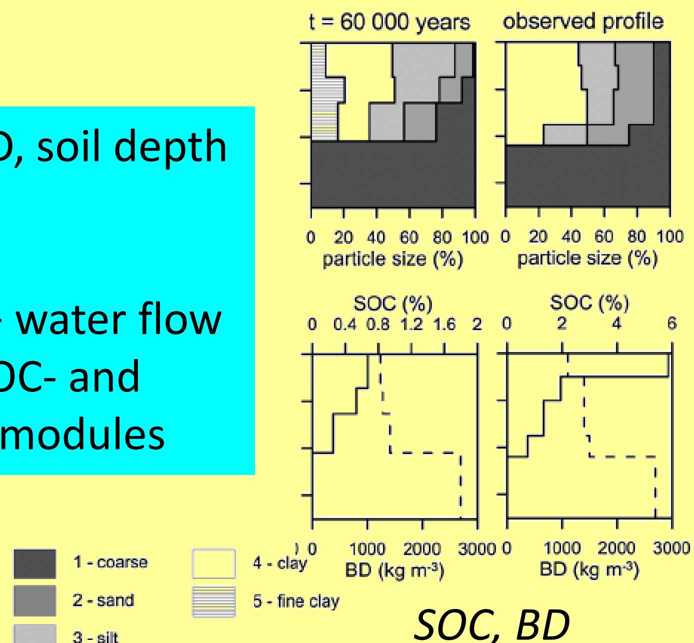
Parameter	Calibration	Visual field data verification
SOC	Vanwalleghem et al., 2013	Vanwalleghem et al., 2013
Layer thickness	Vanwalleghem et al., 2013	Vanwalleghem et al., 2013
Clay, Silt, Sand	Vanwalleghem et al., 2013	Vanwalleghem et al., 2013
BD	Vanwalleghem et al., 2013	Vanwalleghem et al., 2013

Good: Texture, BD, soil depth

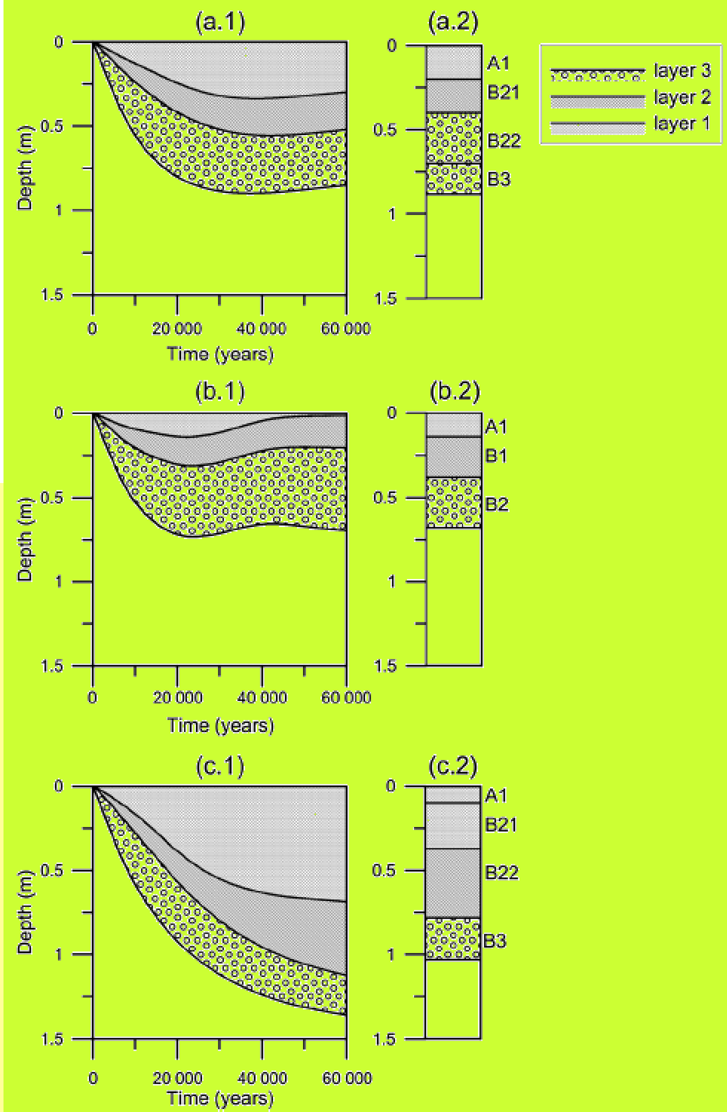
Poor: SOC

Emphasis:

Add heat + water flow improve SOC- and landscape modules



SOC, BD

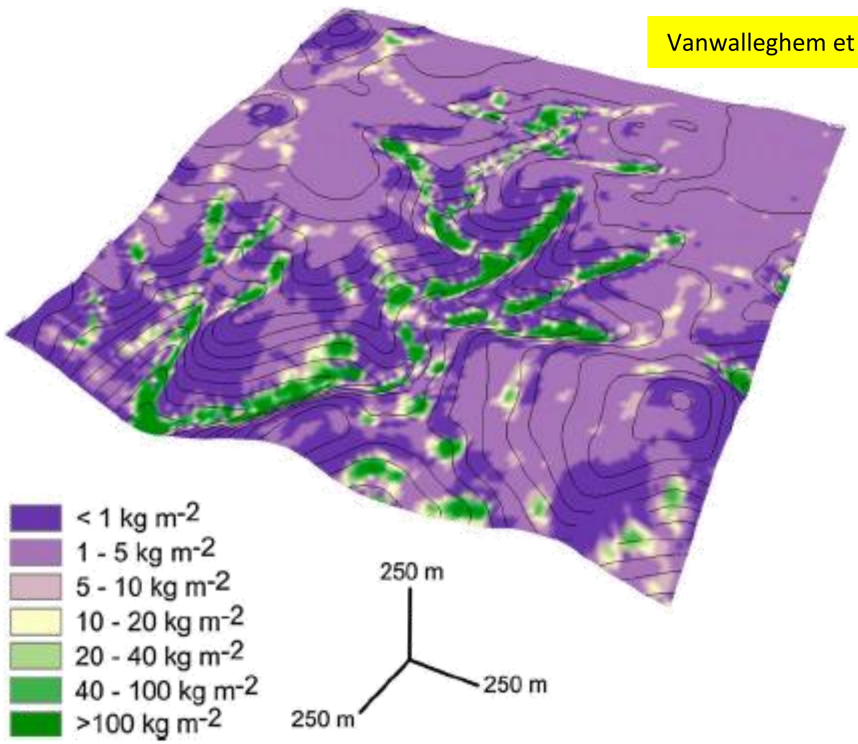


Layer + profile thickness

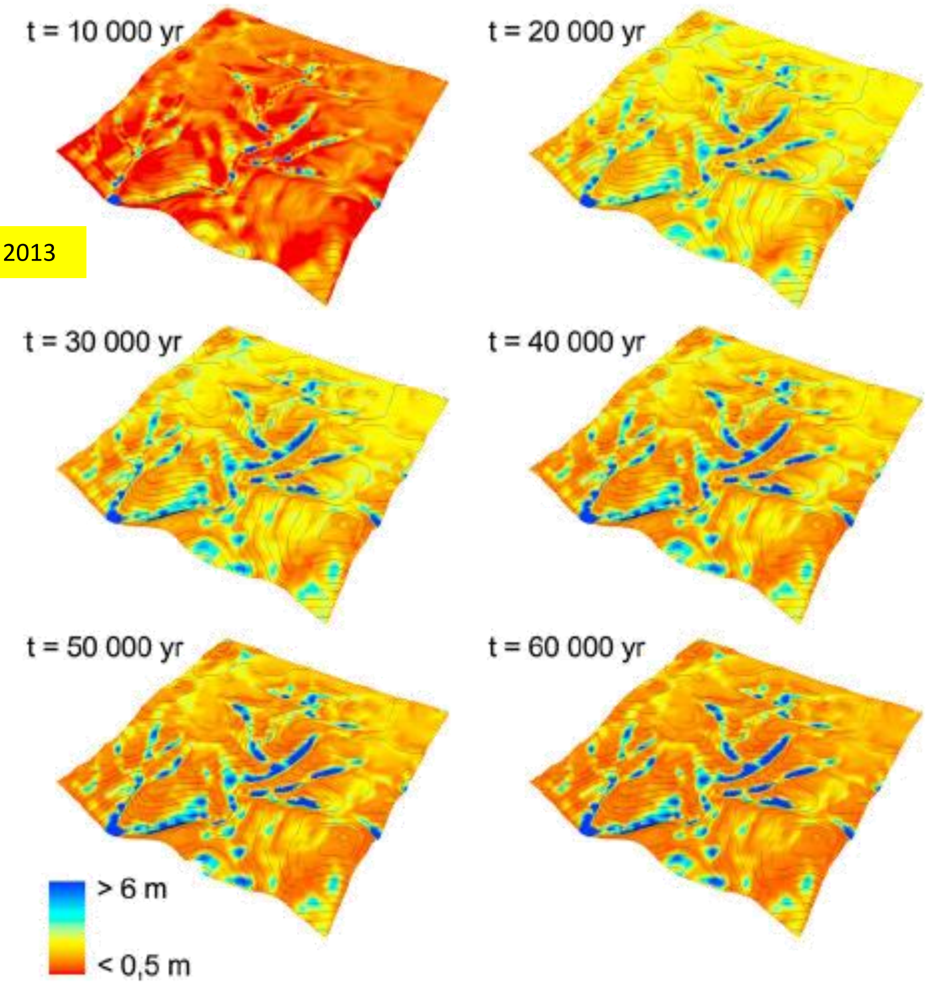
3-D example: *MILESD*

Case soilscape evolution

Vanwalleghem et al., 2013



SOC after t = 60 000 yr



Total soil thickness

Literature scan for model completeness

Case selection:

- WoS-papers on soil(-scape) formation models
- No single-issue models
- 29 cases (1977-2013)

Classified into:

- Pedon (1D+t) models
- Distributed pedon models
- 2D+t models (spatial but no depth discretization, "soil production models")
- 3D+t models (spatial with depth discretization)

Checked for model completeness

- Soil forming processes Bockheim and Gennadiyev (2000)
- Either empirical or mechanistic approaches noted

Checked on field testing

Literature scan for model completeness

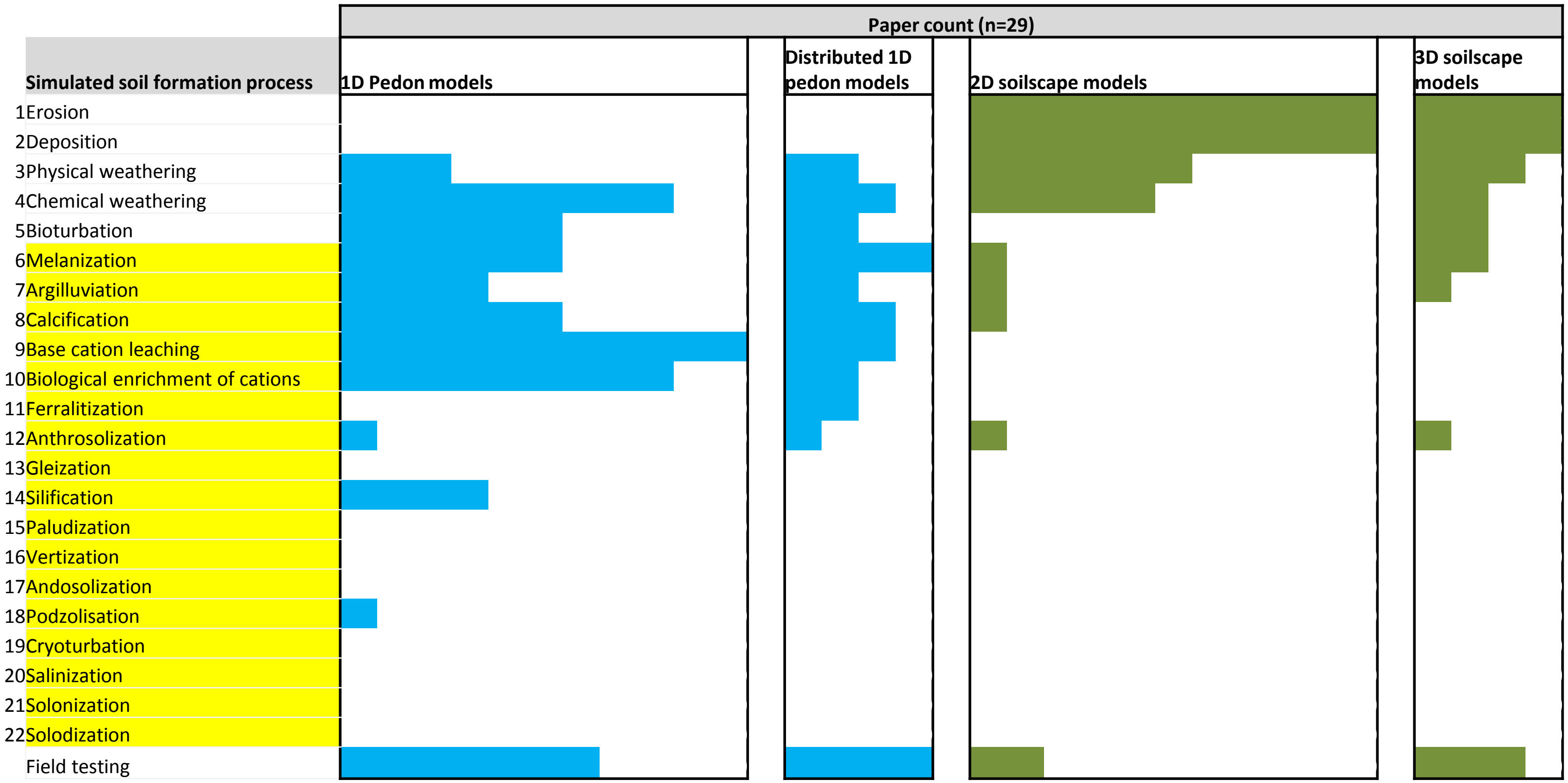
Checklist soil forming processes

	Simulated soil formation process	Description
1	Erosion	Removal of topsoil material
2	Deposition	Addition of material on the topsoil
3	Physical weathering	Reduction in grain sizes due to fragmentation of particles
4	Chemical weathering	Breakdown of primary minerals and -possibly- formation of secondary minerals
5	Bioturbation	Mixing of soil layers by faunal, floral or human activity
6	Melanization	Accumulation of well-humified organic matter within the upper mineral soil
7	Argilluviation	Movement of clay (lessivage)
8	Calcification	Accumulation of secondary carbonates and gypsum
9	Base cation leaching	Eluviation of base cations (Ca, Mg, K, Na) from the solum under extreme leaching conditions
10	Biological enrichment of cations	Vegetation-induced cycling of base-cations
11	Ferralitization	Residual enrichment of Al and Fe and loss of Si by weathering of primary and secondary minerals
12	Anthrosolization	Effects of human activities such as deep working, intensive fertilization, additions of materials, irrigation with sediment-rich waters, and wet cultivation
13	Gleization	Development of reductimorphic or redoximorphic features
14	Silification	Secondary accumulation of Si
15	Paludization	Peat formation: deep accumulation of organic matter
16	Vertization	Shrinking and swelling of soils, evident at the landscape, pedon, and microscopic scales
17	Andosolization	Domination of fine earth fraction by amorphous (Fe, Al) compounds
18	Podzolisation	Movement of organic matter possibly complexed with Fe and Al compounds
19	Cryoturbation	Frost stirring of soil horizons and components under (near-)permafrost conditions
20	Salinization	Accumulation of soluble salts of Na, Ca, Mg, and K as chlorides, sulfates, carbonates, and bicarbonates
21	Solonization	Leaching of excess soluble salts and Na-dominated colloids become dispersed. Soils with a strongly alkaline reaction
22	Solodization	Leaching (argilluviation) of dispersed Na-dominated colloids
	Field testing	

Bockheim and Gennadiyev (2000)

Literature scan for model completeness

Completeness of pedon and soilscape models



- Reasonable but still incomplete process coverage
- Lateral interactions missing
- In most cases driven by water flow
- Field testing quite common

Conditional GC-ready (if 3D and more complete)

- Low process coverage
- Lateral interactions present
- No water flow > mass redistribution=empirical
- Limited field testing

Not GC-ready (until water flow + more complete)

Challenges (1)

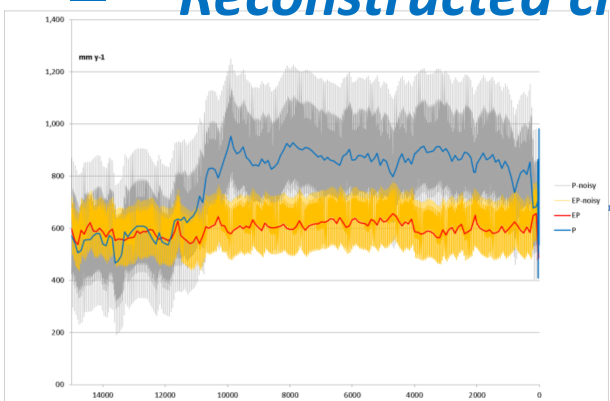
A. 1D+t pedogenetic models:
   - Further increase process coverage
   - Go 3D (computational challenge)
B. 2D+t and 3D+t pedogenetic models:
   - Include hydrology
   - Increase process coverage, decrease empirism
   - Field testing
C. GC-ready soil models need what's missing above
   - Schools need interfacing

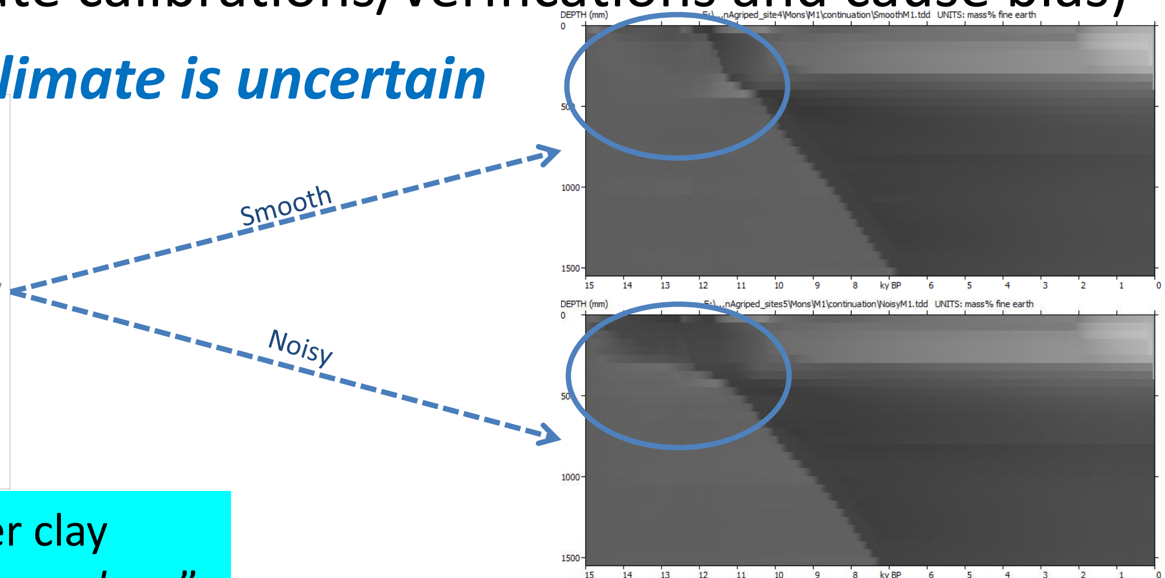
→ IUSS working group "*soilscape genesis modeling*"
http://soillandscape.org/

Challenges (2)

D. Quantify effect of uncertain boundary conditions (may affect final-state calibrations/verifications and cause bias)

– ***Reconstructed climate is uncertain***





Noisy climate: initially stronger clay depletion: *"leaching cannot be undone"*

– ***Reconstructed land use: uncertain age of agriculture***

2000 years of agriculture

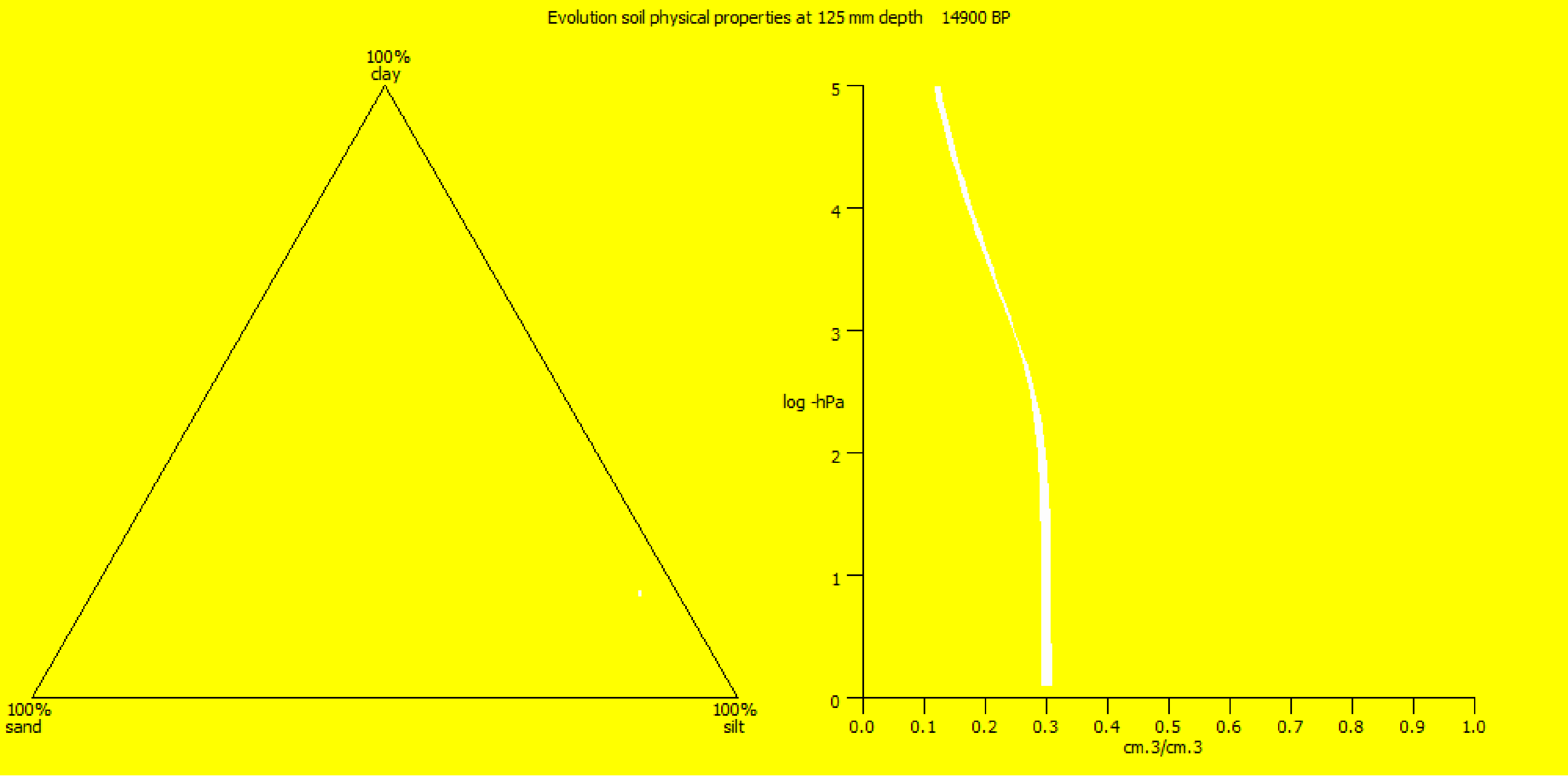
200 years of agriculture

Clay depletion from plow layer is stronger with longer period of agriculture

Challenges (3)

E. Deal with strain (volume change, structure change)

Strong effect of decalcification, change in SOC, lessivage on pF-curve.
Updating h-θ-K by PTF under iso-volumetric assumption (finite differencing) is imprecise.




Thank you
PS:
Water flow drives pedogenesis